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(54) Method of multi-tone printing.

(57) A method of multi-tone printing employs a drop-on-demand printing apparatus (100) for depositing ink droplets on printing element areas of a substrate (111) which is movable relatively to said apparatus. The droplets are deposited from an array of channels (104) on substrate (111) which is movable relatively to the channels. The channels length and nozzle location and dimensions afford each channel with a high longitudinal resonant frequency and electrically actuable means (110,112,114,116,118) supply energy pulses to selected channels at or near the resonant frequency of the channels to deposit from each selected channel in the corresponding printing element area of the substrate a number of drops equal to the number of pulses applied thereto, the number of pulses applied being dependent on the tone of printing required. Single channel and colour versions of the invention are also disclosed.

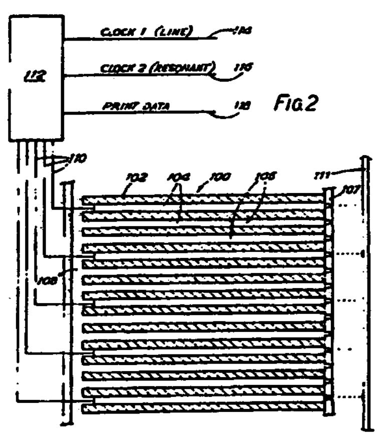

FIG.2

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METHOD OF MULTI-TONE PRINTING

This invention relates to multi-tone printing employing drop-on-demand printing apparatus. More particularly the invention relates to such apparatus for printing droplets on printing element areas on a substrate which is movable relatively to said apparatus and comprises an array of parallel, uniformly spaced channels provided with respective droplet ejection nozzles, a liquid supply means common to said channels and electrically operated means for applying pulses of energy to droplet liquid in said channels to effect droplet ejection there from.

Aspects of such printing apparatus are described for example in United States Patent Specification 4,584,590 and our European Patent Applications Nos. 88300146.3 and 88300144.8 of which the contents of the latter are herein incorporated by reference.

The types of printing apparatus disclosed in the references quoted are of the kind in which energy pulses are imparted to droplet liquid by displacement of wall portions of the respective droplet liquid channels. The present invention is, however, also applicable to drop-on-demand printing apparatus having an array of channels such as is known from US-A 3,179,042, GB-A-2,007,162 and GB-A-2,106,039 in which droplet ejection is effected from the channels by applying a pulse of, thermal energy to droplet liquid therein.

It is known that the human eye can sense sixty-four gradations of greyscale in multi-tone printing. It is even suggested that as many as 128 gradations can be discriminated. Accordingly, it is one aim of high quality tone printing, including colour printing, to produce a printer capable of printing a number of greyscale tones as near as possible to the discriminating capability of the eye of the viewer.

In United States specification 4,513,299 there is disclosed a single channel, drop-on-demand ink jet printing device in which droplets of ink having different droplet volumes can be deposited on a print medium at a droplet repetition rate just below the resonant frequency of the ink channel. The different droplet volumes are achieved by following a droplet ejection pulse with additional droplet ejection pulses of like magnitude to the initial droplet ejection pulse at a frequency at or near the channel resonant frequency. The additional droplet ejection pulses cause ejection from the ink channel of further drop volumes of substantially the same size as the drop volume emitted from the channel by the initial droplet ejection pulse. In the series of drop volumes thus emitted, the second and subsequent drop volumes are each connected to the preceding drop volume emitted and the drop volumes join together to form an enlarged droplet which is deposited on the print medium. However, in high density array drop-on-demand printers, i.e. arrays of at least two parallel channels per mm, the known method of droplet ejection severely limits, to only a few, the number of droplet volumes which can be added to the droplet volume initially ejected from any particular channel. This number diminishes rapidly with increase of channel density. It follows that the number of greyscale gradations which can be achieved by this known method is limited in the achievable number of different drop volumes which can be deposited at a pixel of the printed image.

It is, accordingly, an object of the present invention, to provide an improved method of greyscale printing which employs a drop-on-demand printer having an array of parallel channels which enables printing of a substantially greater number of greyscale gradations than has been achievable hitherto.

The present invention consists in the method of multi-tone printing employing drop-on-demand printing apparatus for depositing ink droplets on printing element areas of a substrate which is movable relatively to said apparatus, comprising an array of parallel uniformly spaced channels provided with respective droplet ejection nozzles, an ink supply common to said channels, and electrically actuable means for applying pulses of energy to ink in said channels to effect droplet ejection therefrom, characterised by choosing the length of said channels and the dimensions and location of said nozzles to afford channels of high longitudinal acoustic resonant frequency and applying in successive periods to ink in respective numbers of channels selected for actuation in each of said periods, by said electrically actuable means, respective sequences of pulses of energy of amplitude and frequency to cause droplet ejection from the selected channels at or near the resonant frequency of the channels, each sequence of pulses containing a number of pulses to eject a corresponding number of discrete droplets, said number being determined by the tone of printing required to be effected on the printing element area on which said droplets are deposited.

Suitably, said electrically actuable means effect droplet ejection from said channels by displacement of respective side wall portions thereof.

Alternatively, said electrically actuable means effect droplet ejection from said channels by causing thermal stress in the ink therein.

Preferably, where the substrate is continuously moving during printing, droplet deposition from each channel takes place over a length of said substrate which is within a printing element area traversed during

printing by the channels. Suitably, droplet deposition on said substrate from each channel takes place over approximately two thirds of the pitch of the printing element areas in the direction of relative motion of the apparatus and substrate and is symmetrically disposed with respect thereto. The pitch in the direction of relative motion between the subs trate and the printing apparatus of the printing element areas is suitably made equal to the ink channel pitch.

In one form, the method of the invention is practised with a printhead comprising a body of piezo-electric material in which said channels are formed and opposed channel dividing side walls of each of said channels have respective piezo-electric portions which are displaceable in shear mode by operation of said electrically actuable means to effect droplet ejection from said channel. When such a printhead is employed, according to said one form of the invention, the channels are divided into a plurality of groups of interleaved channels and droplet ejection is enabled in each group simultaneously from selected channels, the channels selected in such group being actuated in successive phases of the frequency of the applied energy pulses. In one form the channels are arranged in two groups and selected channels of said two groups are enabled for droplet ejection at intervals of half a cycle of the frequency of pulses applied by said electrically actuable means to the channels selected for droplet ejection.

Where colour printing is required, the method of the invention consists in arranging the array of channels in a set or sets of four rows of channels, the rows of each set being respectively supplied with black ink and ink of the three primary colours and disposing the rows of each set for printing a row of printing element areas extending transversely to the direction of relative motion of the array and the substrate so that each area printed can be printed in black ink or ink of one of the three primary colours.

The invention is not however restricted to array apparatus. Thus the invention also consists in the method of multi-tone printing employing drop-on-demand printing apparatus for depositing liquid droplets on a printing element area of a substrate, comprising a liquid channel provided with an ejection nozzle, droplet liquid supply means connected with said channel and electrically actuable means for applying pulses of energy to liquid in said channel to effect droplet ejection therefrom, characterised by choosing the channel dimensions and the dimensions and location of the nozzle so that said channel has a high longitudinal acoustic resonant frequency and applying to liquid in said channel by said electrically actuable means, one or a sequence of pulses of energy of amplitude and frequency to cause droplet ejection from the nozzle of said channel at or near the resonant frequency of said channel thereby to eject a number of droplets from said nozzle corresponding to the number of pulses applied to the liquid in said channel, said number of pulses being determined by the tone of printing required to be effected in said printing element area. In this form of the invention the subs trate would normally be held stationary relatively to the apparatus during printing. Also in this form of the invention colour printing can be effected by providing four channels respectively supplied with black ink and ink of the three primary colours, the nozzles of said channels being arranged so that each printing element area can be printed with any one of said inks.

The invention further consists in a multi-channel array, electrically pulsed droplet deposition apparatus. comprising a multiplicity of parallel channels, mutually spaced in an array direction normal to the length of the channels, said channels having respective side walls which extend in the lengthwise direction of the channels, and in a direction which is both normal to said lengthwise direction and normal to the array direction, respective nozzles communicating with said channels for ejection of droplets of liquid, connection means for connecting said channels to a source of droplet deposition liquid and electrically actuable means located in relation to said channels to effect, upon actuation of any selected channel, application of pulses of energy to droplet liquid in said selected channel to effect droplet ejection from the nozzle communicating therewith, characterised in that said channels have length dimensions and nozzle dimensions and locations to afford channels of high longitudinal acoustic resonant frequency and said electrically actuable means are adapted to apply in successive periods to droplet liquid in respective numbers of channels selected for actuation in each of said periods respective sequences of pulses of energy of amplitude and frequency to cause droplet ejection from the selected channels at or near the resonant frequency of the channels, each sequence of pulses containing a number of pulses to eject a corresponding number of discrete droplets, said number being determined by the tone of printing required to be effected from the channel.

Suitably, said channels include respective displaceable side wall portions and said electrically actuable means are adapted to effect displacement of said side wall portions to impart said energy pulses to droplet liquid in the channels.

Said channels are advantageously arranged in a plurality of groups of interleaved channels, the channels of the respective groups being disposed in repeated sequences and said electrically actuable means are adapted to cause selected channels of each group to be enabled for actuation simultaneously and to effect enabling of the groups of channels in successive intervals of duration to allow ejection of several drops from the enabled channels.

Advantageously, the channel length, channel nozzle diameter and channel density of the apparatus lie respectively in the range 10 to 1mm, 20 to 10μm and 2 to 12 per mm. For any particular printhead apparatus, the said dimensions are chosen to provide channel resonant frequencies of above 25 KHz. Preferably, the chosen resonant frequency is in the range 50 KHz to 250 KHz.

The invention further consists in an electrically pulsed droplet deposition apparatus, comprising a liquid channel having an ink ejection nozzle, droplet liquid supply means connected with said channel and electrically actuable means for supplying pulses of energy to liquid in said channel to effect droplet ejection therefrom, characterised in that the dimensions of the channel and the dimensions and location of the nozzle are adapted to provide the channel with a high longitudinal acoustic resonant frequency so that application to ink in the channel of one or a sequence of pulses of energy of amplitude and frequency at or near the resonant frequency of the channel causes ejection of droplets corresponding in number to said applied pulses whereby the number of droplets deposited from the nozzle can be selected to correspond with a desired tone of printing.

Suitably, translating means are provided for moving the channel or group of channels relatively to a substrate to be printed.

In this manifestation of the invention where colour printing is required there are provided four channels respectively supplied with black ink and ink of the three primary colours, the nozzles of the channels being arranged so that any printing element area of a substrate can be printed with any one of said inks.

In a further form, the invention consists in a drop-on-demand printing apparatus for depositing ink droplets on a substrate comprising an array of printing channels provided with respective nozzles for depositing ink droplets on respective printing element areas of said substrate, ink supply means connected with said channels and electrically actuable means for applying pulses of energy to ink in said channels to effect droplet ejection therefrom, characterised in that the length of the channels and the location and dimensions of the nozzles provide the channels with high longitudinal resonant frequency so that application to ink in the channels of a pulse or sequence of pulses of energy of amplitude and frequency to cause droplet ejection from the channels at or near the resonant frequency of the channels causes ejection of droplets from the channels corresponding in number to the number of energy pulses applied to the ink therein whereby the number of droplets deposited from each nozzle can be selected to correspond with a desired tone of printing and effect printing with the substrate stationary relatively to the apparatus.

The invention will now be described, by way of example, with reference to the accompanying drawings, in which:-

FIGURE 1 illustrates the effect of depositing in successive printing element areas, that is to say, pixels, as the print medium moves past a nozzle of a channel of a drop-on-demand ink jet printer, a variable number of ink drops between 1 and 64;

FIGURE 2 illustrates diagrammatically one embodiment of the invention; and

FIGURE 3 illustrates diagrammatically, in another embodiment of the invention, the printing of a line of printing element areas or pixels from a group of ten channels, the respective nozzles of which eject bursts of varying numbers of droplets between 1 and 64.

The method of the invention can be performed by a drop-on-demand ink jet printing apparatus comprising an array, preferably a high density array, of parallel uniformly spaced channels provided with respective droplet ejection nozzles, an ink supply common to said channels and electrically actuable means for displacing respective piezo-electric side wall portions of said channels to effect droplet ejection from the channels. In the prior United States specification No. 4,584,590 referred to the displaceable piezo-electric side wall portions are provided as the top or roof walls of the respective channels, the channel density being up to two per mm, whereas in our co-pending European patent application No. 88300146.3 there is described e.g. with reference to Figs. 2(a) - (d), a form of printhead in which said displaceable piezo-electric wall portions comprise the channel dividing side walls. In this latter case each of the channel dividing side walls is shared between the channels which it separates so that in a first of successive phases of operation it can be deflected together with the facing wall of one of the channels which it separates to eject a droplet from said one of the channels whilst in a succeeding phase of the operation the said channel dividing wall together with the facing side wall of the other of the channels which it separates can be deflected to eject a droplet from said other of the channels. The channel densities of such printheads can be from 2 to 16 per mm. Hitherto, the operation of this form of printhead has been limited to the application of a voltage waveform pulse which acts to eject a single drop of ink from the channel to which the pulse is applied. The present invention calls for droplet ejection from the channels at high frequency at or near the longitudinal acoustic resonant frequency of the channels. Accordingly the channel length and nozzle dimensions have to be chosen to that end.

Printheads of the kind described can also be employed according to this invention as greyscale and,

therefore, colour printers. An acceptable range of resolution of printing element areas or pixels on a paper subs trate for a printhead as described in our co-pending European patent application referred to would be 6 to 12 per mm. In the area corresponding to each pixel, a variable number of droplets in the range 1 to 64 is made available as hereinafter described.

Typical values of ink drop parameters at each channel nozzle and on the paper substrate area are as follows:-

Resolution of Printhead	Pitch of Nozzles	Full 64 Droplet Volume	Single Drop Volume	Single Droplet Diameter	Droplet Frequency
-/mm	µm	pl	pl	µm	kHz
12 6	83 167	33 130	0.51 2.04	10 15.7	180 90

The full size drop volume, which forms a pool of 64 single ejected small droplets on the paper substrate is chosen to form contiguous dots at full tone.

Figure 1 shows the effect of depositing a variable number of ink droplets between 1 and 64 in successive pixels as the paper moves past the nozzle. Typically, the maximum droplet production frequency is sufficient to generate 100 droplets per pixel, so that if 64 droplets are generated, these are deposited in a line occupying approximately 2/3 of the pixel pitch "p". When smaller numbers of droplets are generated as a sequence these are deposited along correspondingly shorter lines.

From the above table of typical values and assuming there are 100 droplets able to be generated per pixel, the spacing between droplets deposited longitudinally in each pixel, for twelve pixels per mm, is 0.83 µm and for six pixels per mm is 1.67 µm. Laterally the nozzle pitch is equal to the pixel pitch. The spacing in the lines in which they are deposited of the small droplets is small compared with the diameter of the small droplets, 0.83 µm compared with 10 µm for twelve pixels per mm and 1. 67 µm compared with 15.7 µm for six pixels per mm. Also, the period during which a droplet sequence is ejected, i.e.

$$\frac{64 \times 10^3}{180000} = 0.35 \text{ msec.}$$

for 12 pixels per mm and

$$\frac{64}{90000} \times 10^3 = 0.7 \text{ msec}$$

for six pixels per mm is short compared with the time, of a few milliseconds, that ink takes to be absorbed into the paper substrate.

Thus the deposited lines of ink droplets in each pixel have time to collect and spread as dots on the paper surface. The line in which the droplets from any particular nozzle are deposited has little effect on the shape but only on the diameter of the dot formed at the pixel. Figure 1 shows that the relative timing of the deposition of the lines of droplets at the pixels is chosen so that each drop sequence, is deposited symmetrically with respect to the corresponding pixel. This reduces any distortion in the image which could result in contouring and inhibits any tendency to merging of the droplets deposited at adjacent pixels.

Referring now to Figure 2, there is illustrated therein a printhead 100, which is generally similar to that described in relation to Figures 2(a) to (d) of co-pending European Application No. 88300146.3 the contents of which are herein incorporated by reference. The printhead 100 comprises a sheet of piezo-electric material poled in a direction normal thereto and formed with parallel channels 104 at a density of two or more per millimetre having channel dividing side walls 106. The channels 104 are each lined with a metal electrode layer (not shown). The channels which are arranged in three groups of interleaved channels with the channels of the groups disposed successively, are actuated in shear mode by applying an electric potential difference between the electrode layer of an actuated channel and the electrode layers of the channels on either side of the actuated channel. The potential difference applied is a signal of frequency at

or near the longitudinal acoustic resonant frequency of the channels and is applied for the duration of a number of pulses of the signal corresponding to the number of droplets which it is desired to eject from the actuated channel. The channels are supplied with printing liquid from a common supply duct 108 connected with each channel at the end thereof opposite that at which is located a nozzle plate 107 formed with respective nozzles 109 which terminate the channels. The nozzles of each group are co-linearly disposed transversely to the direction of movement of a substrate (111), e.g. paper and the groups of nozzles are spaced in the direction of substrate movement.

Figure 2 illustrates circuitry for operating channels of one of the three channel groups. This comprises connections 110 to the electrodes of the channels of the group, like connections (not shown) being made to the electrodes of each of the channels of the other two groups.

The connections 110 lead to the channels 104 from a processor 112 which is supplied with clock pulses from a conductor 114, the pulses on which in sequence enable the connections 110 to the respective groups of channels. A further clock line conductor 116 provides the processor with clock pulses at a frequency at or near that of the longitudinal acoustic resonant frequency of the channels. Print data in the form of multi-bit words (a) instructs the processor as to which channels of the group of channels which are enabled by the pulse on the conductor 114 are to be selected for actuation, (b) activates the selected channels each with a number from 1 to 64 of pulses at the frequency supplied by way of the conductor 116, and (c) locates the pulses activating the selected channels centrally in the period during which the connections 110 of the group are enabled.

The frequency of pulses supplied by way of the conductor 114 is one-hundredth that of the pulse frequency supplied by way of conductor 116 and the period of the pulses at the frequency supplied via conductor 116 is equal to the time taken for successive pixels on the substrate to pass the channel nozzles. It will be apparent that clock line conductor 114 is not strictly necessary since the processor can be arranged to afford pulses, divided from the pulses supplied by way of conductor 116, for enabling the connections 110 to the channels of each group at a frequency of one-hundredth that of the frequency supplied by way of the conductor 116.

It will also be appreciated that at any instant during operation, an actuated channel is separated from the next nearest actuated channel by at least two inactive channels. Because of this crosstalk between channels is reduced and risk of spurious droplet ejection from inactive channels adjacent actuated channels is avoided.

The spacing, referred to above, of channel nozzles of each group in the direction of printing subs trate movement compensates for the time interval between the actuation of the selected channels of the groups so that printed spots deposited at the pixels of each row thereof transverse to substrate movement appear substantially collinear,

Figure 3 illustrates diagrammatically an alternative manner in which the droplets are ejected from the nozzles of ten channels of a segment of a high density array printhead of the type described in our co-pending European patent application No. 88300146.3, for example, with respect to Figure 2(a) to (d) thereof. The channels here are arranged in two groups of interleaved odd and even numbered channels. To activate a set of adjacent channels, the selected channels of one group are activated by applying a resonant waveform in alternating phase with the channels of the other group. Thus drops are ejected from channels of the two groups in numbers depending on the number of waveforms applied in alternating phases of the resonant waveform as the dividing walls pressurise channels of the interleved groups alternately.

In Figure 3 the densities at pixels opposite the ten channel nozzles are for channels 1 to 10 respectively 64, 64, 60, 55, 40, 32, 17, 8, 5 and 1 droplets. A single pixel in the direction of relative motion between the printhead and paper subs trate is traversed in a period which is equal to the period of 100 cycles of the resonant frequency of the channels, i.e. for the frequencies 180 kHz and 90 KHz of the table set out above of typical values, respectively, 0.55 and 1.11 msecs. These times are those which it would take to emit 100 droplets from each channel. The dots in the drawing represent droplets a maximum of 64 of which are deposited from any particular channel per pixel and the actuation of the channels is preferably arranged so that the droplets deposited from any particular channel are symmetrically deposited with respect to the pixel being printed, that is to say the centre of the pixel is traversed after the elapse of fifty of the hundred cycles allocated to that pixel The lateral pitch of the channel nozzles is made equal to the longitudinal pitch of the pixels traversed by each nozzle

Thus in each pixel period, i.e. the period in which, if supplied to the electrodes of any particular channel, the applied voltage pulses would generate 100 droplets, the number of droplets from each channel would be between one and sixtyfour in the numbers stated earlier.

The droplets are ejected from the selected odd numbered channels as a result of actuation of the channels during the positive parts of the cycles and the selected even numbered channels are actuated one

half cycle following, that is to say, out of phase with, activation of the selected odd numbered channels.

Printing starts with the pixels having the maximum number, i.e. 64, of droplets which are the pixels traversed by the nozzles of channels 1 and 2 and the timing of droplet deposition proceeds as follows:

Cycles	Channels Depositing Drops	Cycles	Channels Depositing Drops	Cycles	Channels Depositing Drops
0 to 18	NIL	$30_{1/2}$	2,4	$42_{1/2}$	2,4,6
19	1	31	1,3,5	43	1,3,5,7
$19_{1/2}$	2	$31_{1/2}$	2,4	$43_{1/2}$	2,4,6
20	1	32	1,3,5	44	1,3,5,7
$20_{1/2}$	2	$32_{1/2}$	2,4	$44_{1/2}$	2,4,6
21	1,3	33	1,3,5	45	1,3,5,7
$21_{1/2}$	2	$33_{1/2}$	2,4	$45_{1/2}$	2,4,6
22	1,3	34	1,3,5	46	1,3,5,7
$22_{1/2}$	2,4	$34_{1/2}$	2,4	$46_{1/2}$	2,4,6
23	1,3	35	1,3,5	47	1,3,5,7
$23_{1/2}$	2,4	$35_{1/2}$	2,4,6	$47_{1/2}$	2,4,6,8
24	1,3	36	1,3,5	48	1,3,5,7,9
$24_{1/2}$	2,4	$36_{1/2}$	2,4,6	$48_{1/2}$	2,4,6,8
25	1,3	37	1,3,5	49	1,3,5,7,9
$25_{1/2}$	2,4	$37_{1/2}$	2,4,6	$49_{1/2}$	2,4,6,8
26	1,3	38	1,3,5	50	1,3,5,7,9
$26_{1/2}$	2,4	$38_{1/2}$	2,4,6	$50_{1/2}$	2,4,6,8,10
27	1,3	39	1,3,5	51	1,3,5,7,9
$27_{1/2}$	2,4	$39_{1/2}$	2,4,6	$51_{1/2}$	2,4,6,8
28	1,3	40	1,3,5	52	1,3,5,7,9
$28_{1/2}$	2,4	$40_{1/2}$	2,4,6		
29	1,3	41	1,3,5	etc. etc.	
$29_{1/2}$	2,4	$41_{1/2}$	2,4,6		
30	1,3	42	1,3,5,7	83 t0 100	NIL

It will be apparent from inspection of the above table that the band of actuated channels gradually widens and then narrows. Channel No. 1 thus deposits drops every cycle from cycle 19 to cycle 82, channel No. 2 every half cycle from cycle $19_{1/2}$ to $82_{1/2}$, channel No. 3 every cycle from cycle 21 to cycle 80, channel No. 4 every half cycle from cycle $23_{1/2}$ to cycle $79_{1/2}$, channel 5 every cycle from cycle 31 to cycle 70, channel 6 every half cycle from cycle $35_{1/2}$ to cycle $66_{1/2}$, channel 7 every cycle from cycle 42 to cycle 58, channel 8 every half cycle from cycle $47_{1/2}$ to $54_{1/2}$, channel 9 every half cycle from cycle 49 to cycle 53, and channel 10 at half cycle $50_{1/2}$.

By reducing the period in which a pixel is traversed and reducing the density of printing, it becomes possible to simulate the laying down of lines of varying linear density.

Although in operation of either of the described embodiments of the invention the frequency of operation, which may be in the range 25 to 250 KHz, and the small size of nozzle employed tend to ensure that the drop sequences emitted from the nozzles comprise separate drops, there may be an inclination for the first few drops of a sequence to merge. This can be avoided by applying initial sub-threshold resonant waveforms or by increasing the energy content of the first few pulses applied by the electrically operated means of the printhead to the channel selected for droplet ejection.

It is to be noted that the embodiment of Figure 3 represents a higher speed (x3) embodiment of printhead. However it is limited in the range of patterns it will print, to a maximum spatial frequency. It will print "white, black, white" but not "black, white, black" across the row of channels. Differently expressed, the embodiment of Figure 3 with a density of nozzles at 12 per mm. prints any pattern at spatial frequencies of and below 4 lines per mm: but is restricted in the patterns that can be printed at spatial frequency of 6 lines per mm. The embodiment of Figure 2 does not have such a restriction but operates more slowly.

In the embodiments of the invention described with reference to Figures 2 and 3 the pulses of energy

applied to the printing liquid in the channels of the array are obtained by the use of electrically displaceable channel side walls. Fluid resonance in the channels of the printhead can however be accomplished in other ways. For example, as earlier referred to, thermal energy pulses can be imparted to liquid in the channels for droplet ejection. To perform the present invention the pulses would be applied at or near the natural longitudinal resonant frequency of the channels, the length and channel dimensions of which would be made such as to provide the requisite high resonant frequency above 25KHz. At relatively low specific energy, the energy coupling to the liquid in the channels involves thermal expansion and contraction of the liquid and, above a specific energy threshold, the energy input to the channel liquid would cause bubble nucleation and collapse.

Alternative forms of actuation which might possibly be considered involve a fluid which swells in the presence of a field or which becomes solid and thus inhibits displacement in the presence of a field, the resonant energy being applied externally.

Claims

1. The method of multi-tone printing employing drop-on-demand printing apparatus for depositing ink droplets on printing element areas of a substrate which is movable relatively to said apparatus, comprising an array of parallel uniformly spaced channels provided with respective droplet ejection nozzles, an ink supply common to said channels, and electrically actuable means for applying pulses of energy to ink in said channels to effect droplet ejection therefrom, characterised by choosing the length of said channels and the dimensions and location of said nozzles to afford channels of high longitudinal acoustic resonant frequency and applying in successive periods to ink in respective numbers of channels selected for actuation in each of said periods, by said electrically actuable means, respective sequences of pulses of energy of amplitude and frequency to cause droplet ejection from the selected channels at or near the resonant frequency of the channels, each sequence of pulses containing a number of pulses to eject a corresponding number of discrete droplets, said number being determined by the tone of printing required to be effected on the printing element area on which said droplets are deposited.

2. The method as claimed in Claim 1, characterised by said electrically actuable means effecting droplet ejection from said channels by displacement of respective side wall portions thereof.

3. The method as claimed in Claim 1, characterised by said electrically actuable means effecting droplet ejection from said channels by displacement of respective, piezo-electric side wall portions of said channels.

4. The method as claimed in Claim 1, characterised by said electrically actuable means effecting droplet ejection from said channels by causing thermal stress in the ink therein.

5. The method as claimed in Claim 4, characterised by said electrically actuable means effecting droplet ejection from said channels by causing bubble nucleation and collapse therein.

6. The method claimed in any preceding claim, and in which the substrate is moving continuously relatively to the printing apparatus, characterised by effecting droplet deposition from each channel over a length of said substrate within a printing element area traversed by said channel.

7. The method claimed in Claim 6, characterised by effecting droplet deposition on said substrate from each channel in approximately two thirds of the pitch of said printing element areas.

8. The method claimed in Claim 6 or Claim 7, characterised by enabling deposition on each printing element area from the corresponding channel of any number, up to sixty-four, of droplets.

9. The method claimed in Claim 6, Claim 7 or Claim 8, characterised by effecting droplet deposition on said substrate symmetrically with respect to the printing element area printed by said channel.

10. The method claimed in any one of Claims 6 to 9, characterised by effecting substantial equality between the pitch of the printing element areas on the substrate in said direction of relative movement and the pitch of said nozzles.

11. The method claimed in any one of Claims 1 to 3 and 6 to 10 insofar as Claims 6 to 10 are appendant on Claims 1 to 3, in which said apparatus is a printhead comprising a body of piezo-electric material in which said channels are formed and opposed channel dividing side walls of each of said channels have respective piezo-electric portions which are displaceable in shear mode by operation of said electrically actuable means to effect droplet ejection from said channel, characterised by arranging the channels in a plurality of groups of interleaved channels, enabling simultaneously in each group for droplet ejection selected channels thereof and actuating the selected channels of each group in successive phases of the frequency of said energy pulses.

12. The method claimed in Claim 11, and in which the channels are arranged in two groups, characterised

by enabling for droplet ejection selected channels of one of said groups at an interval following enabling of selected channels of the other of said groups of a half cycle of the frequency of pulses applied by said electrically operated means to the channels selected for droplet ejection.

13. The method claimed in any one of Claims 1 to 3 or 6 to 10 insofar as Claims 6 to 10 are appendant on Claims 1 to 3, in which said apparatus is a printhead comprising a body of piezo-electric material in which said channels are formed and opposed channel dividing side walls of each of said channels have respective piezo-electric portions which are displaceable by said electrically actuable means to effect droplet ejection from said channels, characterised by arranging said channels in at least three groups of interleaved channels, each group having between successive channels a channel of each of the other groups and simultaneously enabling for droplet ejection therefrom, droplet ejection of droplets from selected channels of each group being effected in successive intervals.

14. The method claimed in any one of Claims 11 to 13, characterised in that the channel length, channel nozzle diameter and channel density respectively lie in the ranges of 10 to 1mm, 20 to 10μm and 2 to 12 per mm.

15. The method claimed in Claim 14, characterised in that the frequency of pulses applied by said electrically operated means to the channels is above 25KHz.

16. The method claimed in Claim 15, characterised in that said frequency is in the range 50 KHz to 250 KHz.

17. The method claimed in any preceding claim, characterised by controlling the energy content of initial pulses of each of said sequences of pulses to ensure that the droplets emitted by said initial pulses are mutually separated.

18. The method claimed in Claim 1, in which the channels are arranged in a plurality of rows extending transversely to the direction of relative motion of the substrate and the apparatus and the nozzle pitch in each row is a multiple equal to the number of said rows of the pitch of said printing element areas in the direction transverse to said direction of relative motion, characterised by disposing the rows of channel and their nozzles so that the nozzles of one row serve to print picture element areas of a row of such areas on the substrate which are being printed which extends normal to said direction of relative motion which are interleaved with those which the nozzles of the other rows serve to print.

19. The method claimed in any one of Claims 1 to 5, characterised by effecting each printing operation with the substrate and apparatus stationary and causing relative motion between the substrate and the apparatus between successive printing operations to move the substrate relatively to the apparatus by the pitch in said direction of relative motion of the printing element areas.

20. The method claimed in Claim 19, characterised by printing by depositing droplets from the channel nozzles in the centre of each printing element area printed.

21. The method claimed in any preceding claim, characterised by arranging the arrays of channels in a set or sets of four rows of channels, the rows of each set being respectively supplied with black ink and ink of the three primary colours and disposing the rows of each set for printing a row of printing element areas extending transversely to the direction of relative motion of the array and the substrate so that each area printed can be printed in black ink or ink of any of the three primary colours.

22. The method of multi-tone printing employing drop-on-demand printing apparatus for depositing liquid droplets on a printing element area of a substrate, comprising a liquid channel provided with an ejection nozzle, droplet liquid supply means connected with said channel and electrically actuable means for applying pulses of energy to liquid in said channel to effect droplet ejection therefrom, characterised by choosing the channel dimensions and the dimensions and location of the nozzle so that said channel has a high longitudinal acoustic resonant frequency and applying to liquid in said channel by said electrically actuable means, one or a sequence of pulses of energy of amplitude and frequency to cause droplet ejection from the nozzle of said channel at or near the resonant frequency of said channel thereby to eject a number of droplets from said nozzle corresponding to the number of pulses applied to the liquid in said channel, said number of pulses being determined by the tone of printing required to be effected in said printing element area.

23. The method claimed in Claim 22, characterised by holding the substrate stationary relatively to the ink channel during printing.

24. The method of Claims 22 or 23, characterised by providing four such channels respectively supplied with black ink and ink of the three primary colours, the nozzles of said channels being arranged so that each printing element area can be printed with any one of said inks.

25. The method of multi-tone printing employing drop-on-demand printing apparatus for depositing droplets of ink on printing element areas of a substrate comprising an array of printing channels for depositing droplets on respective of said areas corresponding with said channels, nozzles respectively communicating

with said channels, ink supply means connected with said channels and electrically actuable means for applying pulses of energy to ink in said channels to effect droplet ejection therefrom, characterised by choosing the length of said channels and the dimensions and location of said nozzles to afford channels of high longitudinal acoustic resonant frequency, applying to ink in each of a number of said channels selected for actuation one or a sequence of pulses of energy of amplitude and frequency to cause droplet ejection from the nozzles of said selected channels at or near the resonant frequency of the channels thereby to eject from the nozzles of each of said selected channels a number of droplets corresponding to the number of pulses applied to the ink therein, said number of pulses being determined by the tone of printing required in the corresponding printing element areas and effecting printing with the substrate held stationary relatively to the apparatus.

26. The method claimed in Claim 25, characterised by providing for each printing element area of the substrate a group of four channels having respective ink supplies of black ink and ink of the three primary colours thereby to enable printing of each printing element area in black or one of the said primary colours.

27. A multi-channel array, electrically pulsed droplet deposition apparatus, comprising a multiplicity of parallel channels, mutually spaced in an array direction normal to the length of the channels, said channels having respective side walls which extend in the lengthwise direction of the channels, and in a direction which is both normal to said lengthwise direction and normal to the array direction, respective nozzles communicating with said channels for ejection of droplets of liquid, connection means for connecting said channels to a source of droplet deposition liquid and electrically actuable means located in relation to said channels to effect, upon actuation of any selected channel, application of pulses of energy to droplet liquid in said selected channel to effect droplet ejection from the nozzle communicating therewith, characterised in that said channels have length dimensions and nozzle dimensions and locations to afford channels of high longitudinal acoustic resonant frequency and said electrically actuable means are adapted to apply in successive periods to droplet liquid in respective numbers of channels selected for actuation in each of said periods respective sequences of pulses of energy of amplitude and frequency to cause droplet ejection from the selected channels at or near the resonant frequency of the channels, each sequence of pulses containing a number of pulses to eject a corresponding number of discrete droplets, said number being determined by the tone of printing required to be effected from the channel.

28. Apparatus as claimed in Claim 27, characterised in that said channels include respective displaceable side wall portions and said electrically actuable means are adapted to effect displacement of said side wall portions to impart said energy pulses to droplet liquid in the channels.

29. Apparatus as claimed in Claim 27 or Claim 28, characterised in that said channels are formed in a body of piezo-electric material and have side wall portions poled so as to be displaceable by operation of said electrically actuable means.

30. Apparatus as claimed in Claim 29, characterised in that said side wall portions are poled so as to be displaced in shear mode by said electrically actuable means.

31. Apparatus as claimed in Claim 30, characterised in that said channels are arranged in a plurality of groups of interleaved channels, the channels of the respective groups being disposed in repeated sequences and said electrically actuable means are adapted to cause selected channels of each group to be enabled for actuation simultaneously and to effect enabling of the groups of channels in successive intervals of duration to allow ejection of several drops from the enabled channels.

32. Apparatus as claimed in Claim 31, in which all channel dividing side walls are actuable and facing channel side walls are displaced by said electrically actuable means to effect droplet ejection from a channel therebetween, characterised in that the channels are arranged in at least three groups of interleaved channels.

33. Apparatus as claimed in Claim 32, characterised in that said electrically actuable means are adapted to provide that the period that selected channels are enabled by said electrically actuable means is sufficient for ejection therefrom of up to sixty-four droplets.

34. Apparatus as claimed in Claim 28, in which all channel dividing side walls are displaceable and facing channel side walls are displaced by said electrically actuable means to effect droplet ejection from a channel therebetween, characterised in that the channels are arranged in two groups of interleaved channels and said electrically actuable means are adapted to enable simultaneously selected channels of the respective groups and to enable the groups of channels in sequence, the period that channels of the groups are enabled being adequate to allow ejection of several droplets therefrom.

35. Apparatus as claimed in Claim 34, characterised in that said electrically actuable means are adapted to enable droplet ejection from adjacent channels at successive half cycles of the frequency of actuation pulses applied to the channels.

36. Apparatus as claimed in Claim 34 or Claim 35, characterised in that said electrically actuable means are

adapted to enable each channel for a period sufficient for ejection therefrom of up to sixty-four droplets.

37. Apparatus as claimed in any one of Claims 28 to 36, characterised in that the channel length, channel nozzle diameter and channel density respectivly lie in the range 10 to 1mm, 20 to 10μm and 2 to 12 per mm.

38. Apparatus as claimed in Claim 27, characterised in that said electrically actuable means are adapted to cause droplet ejection from said channels by causing thermal stress in the droplet liquid therein.

39. Apparatus as claimed in Claim 38, characterised in that said electrically actuable means are adapted to cause droplet ejection from said channels by causing bubble nucleation and collapse in the droplet liquid therein.

40. Apparatus as claimed in Claim 27, characterised in that the channels are arranged in a plurality of rows extending in operation when said apparatus is printing on printing element areas of a substrate transversely to the direction of relative motion between the apparatus and the substrate and the nozzle pitch in each row is a multiple equal to the number of said rows of the pitch said printing element areas in the direction transverse to said direction of relative motion and said channels and their nozzles are disposed so that the nozzles of each row serve to print picture element areas of a row of such areas on the substrate which are being printed which extends normal to said direction of relative motion and which are interleaved with those which the nozzles of the other rows serve to print.

41. Apparatus as claimed in any one of Claims 27 to 40, characterised in that the array of channels is arranged in a set or sets of four rows of channels, the rows of each set being adapted for the supply thereto respectively of black ink and ink of one of the three primary colours, and the nozzles of the rows of each set are disposed to enable printing of printing element areas by any channel of said set in black ink or ink of any one of the three primary colours.

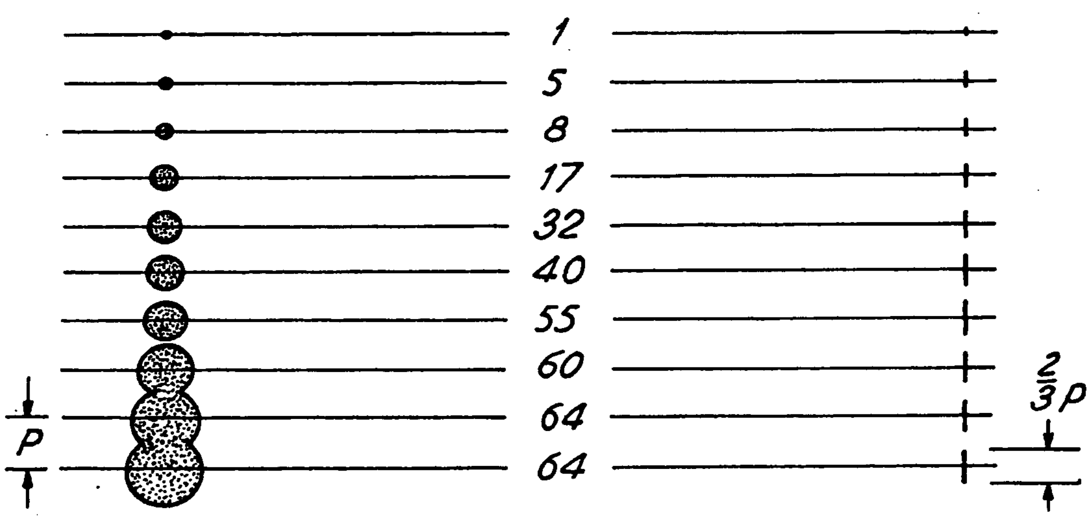
42. An electrically pulsed droplet deposition apparatus, comprising a liquid channel having an ink ejection nozzle, droplet liquid supply means connected with said channel and electrically actuable means for supplying pulses of energy to liquid in said channel to effect droplet ejection therefrom, characterised in that the dimensions of the channel and the dimensions and location of the nozzle are adapted to provide the channel with a high longitudinal acoustic resonant frequency so that application to ink in the channel of one or a sequence of pulses of energy of amplitude and frequency at or near the resonant frequency of the channel causes ejection of droplets corresponding in number to said applied pulses whereby the number of droplets deposited from the nozzle can be selected to correspond with a desired tone of printing.

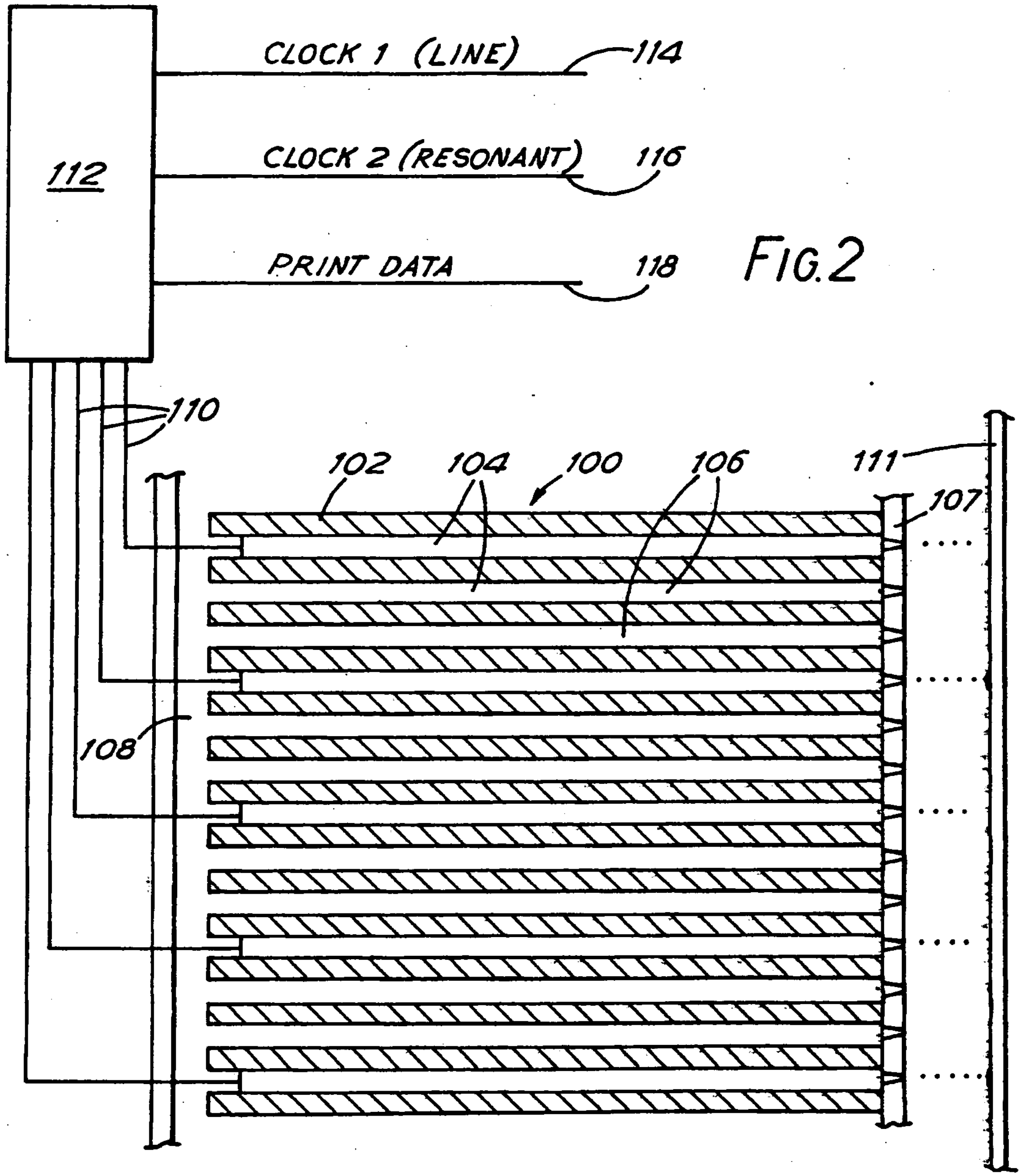
43. Apparatus as claimed in Claim 42, characterised in that there is provided a group of four such channels respectively supplied with black ink and ink of the three primary colours, the nozzles of the channels being arranged so that any printing element area of a substrate can be printed with any of said inks.

44. Apparatus as claimed in Claim 42 or Claim 43, characterised in that translating means are provided for moving the channel or group of channels relatively to a substrate to be printed.

45. A drop-on-demand printing apparatus for depositing ink droplets on a substrate comprising an array of printing channels provided with respective nozzles for depositing ink droplets on respective printing element areas of said substrate, ink supply means connected with said channels and electrically actuable means for applying pulses of energy to ink in said channels to effect droplet ejection therefrom, characterised in that the length of the channels and the location and dimensions of the nozzles provide the channels with high longitudinal resonant frequency so that application to ink in the channels of a pulse or sequence of pulses of energy of amplitude and frequency to cause droplet ejection from the channels at or near the resonant frequency of the channels causes ejection of droplets from the channels corresponding in number to the number of energy pulses applied to the ink therein whereby the number of droplets deposited from each nozzle can be selected to correspond with a desired tone of printing and effect printing with the substrate stationary relatively to the apparatus.

FIG.1

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CLOCK 2 (RESONANT)
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PRINT DATA
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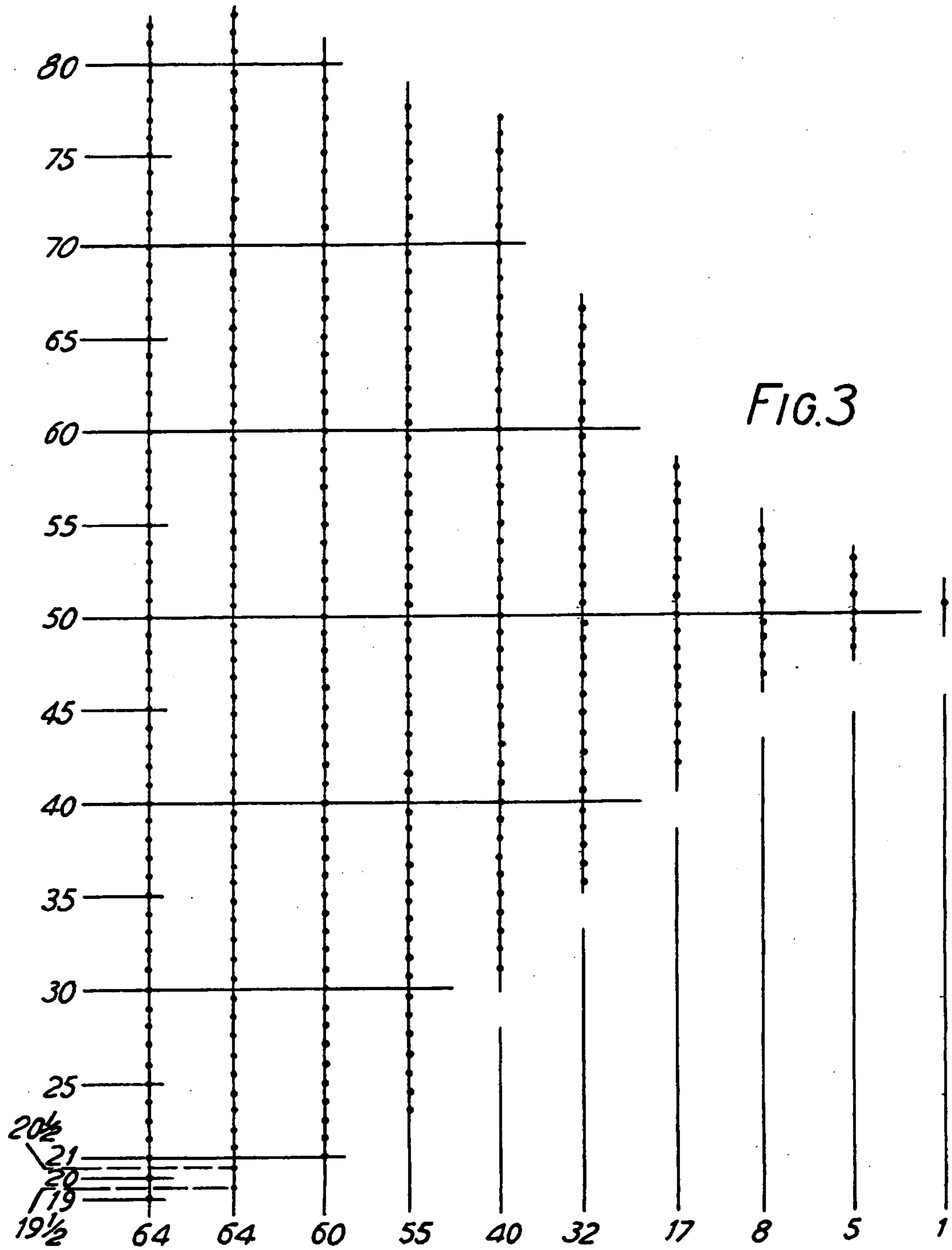
110
102
104
100
106
111
107
108

FIG.2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40
32
17
8
5
1

FIG.3